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THE WELDING JOURNAL

Pages 2-11

April 1936

IMPACT TESTS OF WELDED JOINTS

By

W. Spraragen, and
C.E. Claussen

Respectively Submitted,

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Welding Engineer.

WATERTOWN ARSENAL
WATERTOWN, MASS.

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IMPACT TESTS OF WELDED JOINTS

By W.Spraragen and G.E.Claussen

This article is very good as a survey of world literature on impact testing which has been done. There are certain statements made which appear to need further explanation.

On page 5, the statement is made "The effect of changing the velocity of impact within the usual limits of the machine is also negligible, except possibly in very tough material".

This reference applies probably to the small Charpy machine generally available in industrial laboratories and no evidence is given to support the contention. It is possible that the statement is true for the machine of small capacity but it is not what Mr. Mann has found from tests in the Arsenal Laboratory. I should think that the reference to tough material should rather be brittle material since the critical velocity for brittle material should be lower than that for tough material.

It is not clearly brought out that any form of notched bar test in impact does not test the welded joint as a whole but rather a section of it. Therefore, it is not suitable for testing a joint although for testing the weld metal or plate metal it is perhaps suitable.

Reference is made to attempts to develop formulae showing relation between impact and area of cross-section or diameter of notch. There is evidently a lack of understanding that the impact result obtained varies directly as the volume of the material affected by the test. With the notched bar the volume affected is impossible to accurately determine and hence, the failure to develop formulae.

The statement is made "Elongation and impact value apparently measured the same quality though the impact figure was the more sensitive." Here again impact value is energy in foot pounds which is a product of average force times distance whereas elongation is only one factor of this product, that of distance. It is not possible, therefore, for elongation to vary the same as the impact value unless the average force is a constant figure which is rarely possible.

In discussing notch location, Spraragen includes the specimen used at the Arsenal. Actually, the effect of the notch ceases to be when the length of the notch exceeds approximately 1/4", therefore, our specimen should not produce a notch effect. He discusses this test later under Tensile Impact and makes the criticism that the cross section tested is larger than can be handled by most commercial Charpy machines. Then he goes on further to state that "In view of the extraordinary difficulty in standardizing the well known single-blow, notch-impact test, it is hardly to be expected that the tensile impact, impact fatigue, and other proposed laboratory impact tests of whose characteristics comparatively little is known at present, will soon become prominent." I cannot see why a relationship could be assumed and on what basis, because a tensile impact test appears to be more clearly interpretable than a notched bar impact test.

In discussing correlation of impact results with other physical properties the authors express the various discrepancies, having in mind presumably the notched bar. These discrepancies are the reason why we do not consider the notched bar suitable for testing a welded joint. They state "Perhaps the most significant lack of correlation is between the impact value and the radiograph of a weld" and further, "the standard impact test does not, for example, detect improper fusion along the sides of a V". These are seemingly very excellent reasons why the use of a notched specimen is not suitable for weld testing. It is possible to change the result by changing the location of the notch.

Frequent reference is made to the "zone of transition" and no explanation is given of the meaning of this term.

The authors state "The complaint expressed by some that the scatter of impact results on welds is too large, may be an indication that the test distinguishes almost too sensitively between good and bad welds. For it has been clearly demonstrated that uniform impact results are obtained from uniformly good or uniformly bad welds". It is our contention that the tensile impact test made at the Arsenal is more sensitive to weld quality than any other form of test. With our form of specimen variations of results are due primarily to variations in the welded joint and not due to specimen shape or location of notch as is the case with the notched bar test.

The authors should be complimented on the article they have prepared. It represents a great amount of time and study and is well written.

Possibly one point which might be mentioned in connection with the discussion of service impact tests is that the results of the so-called service impact tests do not apparently bear out results obtained from tests of the welded joints using a notched bar. This seems to be another strong point in favor of eliminating the notched bar for impact tests of welded joints.

Respectively submitted,

W L Warner
W. L. Warner,
Welding Engineer

Impact Tests of Welded Joints

A Review of the Literature to January 1, 1936

By W. SPRARAGEN* AND G. E. CLAUSSEN**

Introduction and Summary

IN MANY engineering applications such as bridges, ships, cranes and piling, welds are subjected to dynamic stresses of an "impact" character. It is important for engineers as well as for others to know to what extent welds are able to withstand such stresses and the relation, if any, between impact resistance and other physical properties and how one may best improve impact resistance of welded joints.

This report as its title indicates is a review of the literature on the subject divided into four main divisions: (1) Methods of making impact tests of welded joints; (2) Results obtained from impact tests; (3) Service tests and results, and (4) Bibliography.

As may be expected, most of the tests have been made with the standard Izod and Charpy specimens, although the results of a number of tensile impact investigations are available. Several European countries require impact tests of welded specimens in codes and specifications. There is no such requirement, as yet, in the United States.

Impact values of welded joints have steadily improved from 4 ft.-lb. for the standard Izod specimen to 40 and 50 ft.-lb. at the present time. There are many important factors which affect the impact test results, notably, type of filler metal, process of welding, method of depositing weld, heat treatment and the avoidance of stress concentrations. Service results indicate conclusively that even welds made with bare wire will withstand severe impact stresses. With superior filler metal by both gas and arc it is possible to produce welds having nearly the same resistance to impact as the base metal. There is a decided lack of information on impact of welds in non-ferrous metals and welds made by the resistance and thermit processes. Meager test results and service experience indicate that good welds by these two last named processes give excellent impact results. Welds subjected to extremely low or high temperature merit special consideration and good results are entirely feasible.

I—Methods of Making Impact Tests

Laboratory Tests

National and Other Standards. The obvious desirability of testing welds for impact resistance has not led to the adoption in the U. S. A. of a standard laboratory impact test. Standard welding specifications of at least five countries, however, contain detailed instructions for the impact testing of welds or welding electrodes. Although all these specifications require a notched-bar specimen in impact bending, there are considerable variations among the specifications in two principal respects:

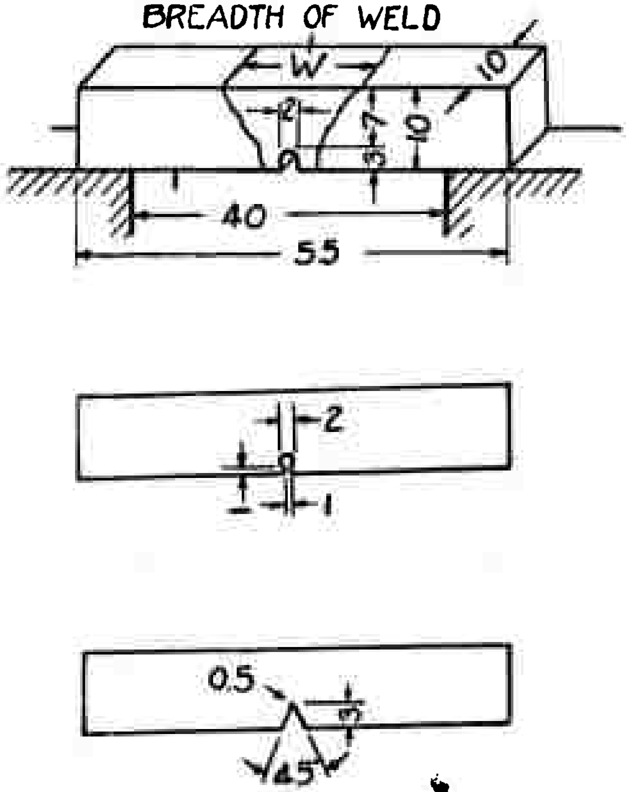

Fig. 1—German Standard Impact Specimens for Gas and Arc Welds. Upper—Round Notch, Milled. Middle—Round Notch, Drill Hole and Saw Cut. Lower—Sharp Notch. (Dimensions in Millimeters)

(1) Type of specimen, Izod or Charpy (Mesnager),
(2) Specimens prepared from an actual welded joint or from all-weld-metal.

Since it appears unlikely that an internationally standardized notch-impact specimen even for unwelded metal will be adopted for some time, the existing differences between specifications may be expected to remain indefinitely.

German

The standard notch-impact test adopted in Germany, from which has come most of the impetus for standardizing the impact test, is described in D. I. N. 1913.[1] An almost identical standard has been adopted in Austria.[2] The standard specimens, shown in Fig. 1, are cut from welds made in horizontal plates 350 x 150 mm. Impact tests are not made on plates thinner than 10 mm. The weld is deposited in a V (70 deg. angle) for plates up to 12 mm. thick and in the form of opening dictated by shop practice for plates thicker than 12 mm. From forgeable welds two specimens are taken, from unforgeable, three specimens. Either the 10 kgm. or the 30 kgm. pendulum machine is used with a hammer angle of 30 deg. Of the three types of notch shown in Fig. 1 the first two are

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** Research Assistant, Fundamental Research Committee.

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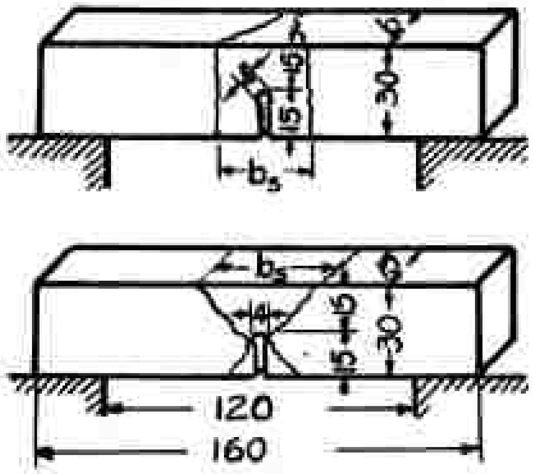
Fig. 2—Notch Impact Specimens. Vereinigung Grosskesselbesitzers (VGB). Dimensions in Mm. Upper Specimens for Plate Thickness
S = 12 to 30 mm. For S = 12 to 15 mm., b = S
For S > 15 mm., b = 15 mm.
In Which Case One Plate Surface Is Not Machined. Lower Specimen for S > 30 Mm.; In This Case the Upper Specimen May Also Be Used



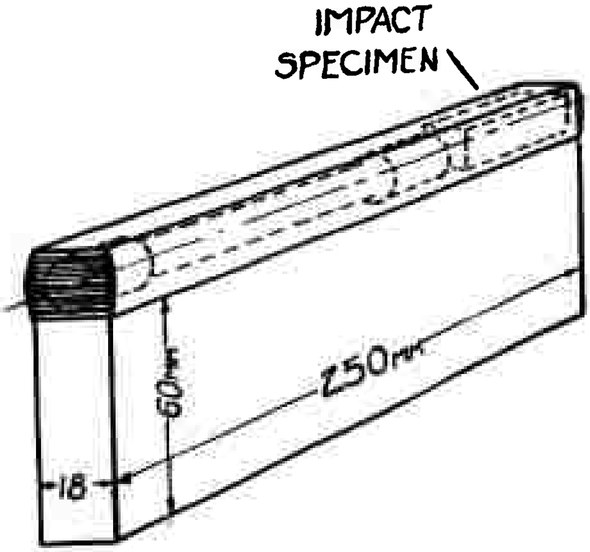


Fig. 3—Standard Method of Preparation of All-Weld-Metal Impact and Tensile Specimens Specified by French Society of Welding Engineers and Others for Gas Welding

ordinarily used; the upper specimen is adopted when the notch is milled, the lower when the notch is drilled and sawn. The sharp-notch alternative specimen is used for tough material that cannot otherwise be broken with a single blow. The round-notch specimens are identical in dimensions with the Mesnager specimen, except that the notch depth is 3 mm. instead of 2 mm. to promote ease in drilling key holes. The impact value is expressed in meter kilograms per square centimeter of cross section back of the notch. In heavy plate over 15 mm. both specimens may be cut from different cross sections of the weld.

Although the impact value is included in the test report, the D. I. N. impact test is not an acceptance test unless it is so specified by special agreement between purchaser and manufacturer. The impact value is considered to indicate (1) the behavior of a material under sudden loads, (2) the character of deformation beyond the elastic region, (3) the degree of forgeability and (4) mistakes in heat treatment (annealing at too high a temperature, etc.).

For welded vehicles the German Federal Railways requires deposits of electrodes and gas welding rods to attain the following values:

Electrodes,	E 34 h	8 mkg./cm.^{2}	unannealed
	E 34 h	10 mkg./cm.^{2}	annealed
	E 37 h	5 mkg./cm.^{2}	unannealed
	E 52 h	5 mkg./cm.^{2}	unannealed
Gas welding	St 34	8 mkg./cm.^{2}	unannealed
rods	St 34	10 mkg./cm.^{2}	annealed
	St 37	5 mkg./cm.^{2}	unannealed
	St 52	5 mkg./cm.^{2}	unannealed

The standard D. I. N. specimen is used but when an old-type machine only is available a specimen may be used of which the length is 100, the distance between supports 70 mm., and other dimensions the same as the D. I. N.

Two other specimens often used in Germany are those prescribed by the Instructions of the Boiler Owners Society (V. G. B.). In addition to the small German standard (D. I. N.), the V. G. B. has adopted two large specimens, shown in Fig. 2. A mechanical aging test is also specified for boiler plate. Prior to testing in impact the weld is stretched 7 to 9% in tension and aged $^1/_2$ hour at 250° C.

French

The standard impact test for gas welds in France is that contained in the Specifications of the Joint Commission of La Société des Ingénieurs Soudeurs and l'Institut de Soudure Autogène drawn up for adoption in January 1936.[3] The specimens adopted, Fig. 3, are identical with the German standard except for notch dimensions. The Mesnager notch is 2 mm. deep; the Charpy notch is 5 mm. deep. The Charpy specimen is that standardized by the Association Française de Norm. The impact test specimens are machined from all-weld-metal deposited in 18 or 20 runs about 1 mm. thick on a plate 15 to 20 mm. thick and 250 x 60 mm. cross section. The specimens must be cut at least 5 mm. from the bottom of the deposit. Torch speed, burner and rod instructions are given. The weld metal must pass the following requirements:

Material	$R \geqslant$	$A \geqslant$	$K \geqslant$	$H \geqslant$	S and $S+P$
A-40	35	20	10	100	$\leqslant 0.04$; $S + P < 0.07$
A-50	45	14	8	120	$\leqslant 0.04$; $S + P < 0.07$
A-60	55	10	6	140	$\leqslant 0.04$; $S + P < 0.07$
A-70	60	8	4	200	$\leqslant 0.04$; $S + P < 0.07$

R—tensile strength, kg./mm.^{2}
A—elongation in % of gage length of 7.2 diameter
K—notch impact value, kgm./cm.^{2}
H—Brinell hardness
S—% sulphur
$S+P$—% sulphur plus phosphorus

The above steels with 0.5% Cu have the same specifications.

These requirements for gas welds are similar to the various specifications for arc welds. For all-weld-metal specimens of 50,000 psi tensile grade an impact value of 5 mkg./cm.^{2} Mesnager specimen is required in marine and general structural work by Le Bureau Veritas.[4] The French standard Charpy is adopted in the Instructions of the Department of Roads and Bridges[5] who require 8 mkg./cm.^{2} for electrodes of both the 50,000 and the 60,000 psi classes.

British

The British standard impact test for arc welds is described in British Standard Specification No. 538-1934.[6] The standard Izod specimen, Fig. 4, is machined from all-weld-metal. Three impact tests are made on every 50,000 ft. of No. 8 S. W. G. electrode or with other sizes an equivalent weight. At least two of the three shall give an impact value of not less than 30 ft.-lb.

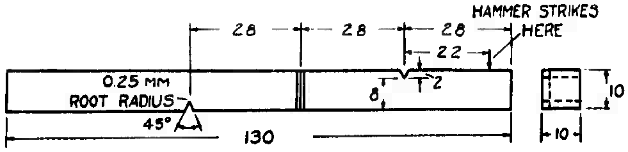


Fig. 4—British Standard Izod Specimen (All-Weld-Metal). Dimensions in Millimeters
Note: The unnotched side of the specimen is that immediately adjacent to the plate on which the metal is deposited.

The standard Izod specimen (three-notch) is also specified by Lloyds Register. Two standard specimens must give an average Izod value of 20 ft.-lb. according to their "Additional Tests for Electrodes Proposed to Be Used for Parts of Primary Structural Importance, 1934–1935."

Australian

Although the Standards Association of Australia[7] also specifies the standard Izod specimen, it is cut from an actual butt-welded joint, Fig. 5. The standard notch is located on the center line of the weld and on the open side of the 90 deg. V. For Australian Structural Grade Electrodes the average Izod value of 5 specimens must be not less than 30 ft.-lb.; for Ordinary Grade the minimum is 20 ft.-lb. The specifications of the Northwestern Railway, India, contain conditions and requirements for impact specimens that are identical with S. A. A. No. CA 8.

The S. A. A. Boiler Code CB 1 No. B 28–1931 and No. B 29–1931 uses a standard Izod specimen milled from butt-welded plates having a 70 deg. V. Five unannealed specimens must average at least 25 ft.-lb. both for arc and gas welds.

Discussion

So far as can be ascertained, the national standards of all other countries, including France, specify no impact tests for welds. Furthermore, all the standards that have been described relate to steel and to specimens that have been machined on all sides. The impact test for welded joints was deleted from the final form of the A. S. M. E. Boiler Code because the Code Committee determined that only welds having satisfactory impact value could meet the Code's physical requirements.

Comparison of the standard tests with each other shows that there is lack of agreement between the different standardizing bodies on two major issues.

1. Whereas the impact test for unwelded material standardized in the countries of Continental Europe is the Charpy, that adopted in Great Britain and Australia is the Izod. It is therefore natural that a similar division should exist in the impact test for welds. The Charpy keyhole notch is fundamentally superior to the Izod nick but is somewhat more expensive to machine.

2. The intention of the standard impact tests on all-weld-metal is solely to test the quality of the welding rod as reflected in the cast deposit. The aim of the tests using actual joints appears to be to test the quality of the deposit in contact with parent metal. In the latter instance, normal welding conditions are reproduced but the absorption of impact energy by parent metal must be anticipated, especially in specimens notched on the open side of the weld. Results from specimens notched on the root side average the impact-absorbing capacity of the annealed inner and the unannealed outer layers of arc welds.

Other Impact Tests for Welds

Although much of the research on impact properties of welds has been performed on standard specimens of the notched type, a number of investigators have used specimens of their own design or other methods of testing impact properties, and a few have studied the effect of variations from standard specimens in an effort to improve their sensitivity. Of this last group the work of Schuster[8] on the Izod specimen, who showed that a 10 x 5-mm. Izod specimen with 1-mm. notch depth was as sensitive as the standard Izod for actual joints, of the British Engine, Boiler and Electrical Insurance Company[9] whose results on 10-mm. and 8-mm. Izod specimens reveal no simple conversion factor, and of Dustin,[10] and Bardtke and Matting[11] on the Charpy type appear most important.

Dustin showed that the standard Mesnager and Charpy specimens for welded joints gave relatively little scatter but that the Charpy was slightly better in this respect, that nothing was to be gained by increasing the dimensions of the standard specimens, and that varying the proportion of weld metal to parent metal in the specimen within wide limits had no effect on impact value. Elongation and impact value apparently measured the same quality though the impact figure was the more sensitive. Dustin's results made it clear, however, that impact tests on specimens whose "zone of transition" occurred in the neighborhood of room temperature were likely to be erratic and misleading. The disturbing effect of this narrow zone of temperatures, which is a characteristic of steel and in which impact value, apparently related to the variation with temperature of the ratio of shear to tensile stress developed in the Izod or Charpy test, falls from a high to an exceedingly low value within a range of perhaps 30° C., is acute in materials of heterogeneous grain size and composition.

From a short series of tests on various forms of specimens in which dimensions of specimen were changed as well as the location of notch with respect to weld, Bardtke and Matting report in favor of the D. I. N. Mesnager specimen with 3-mm. notch depth. The drilled notch

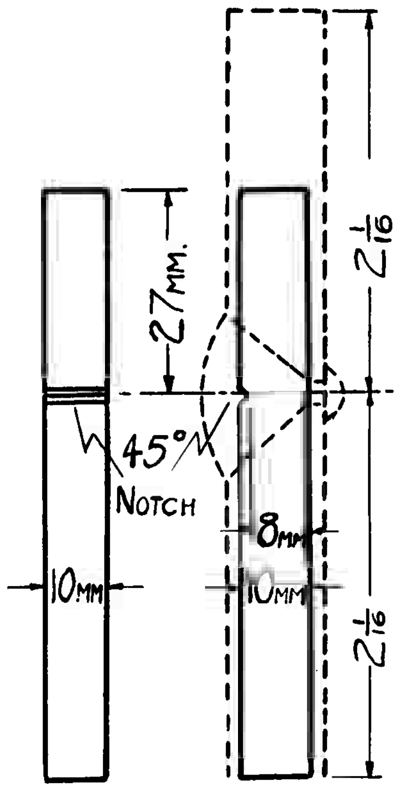
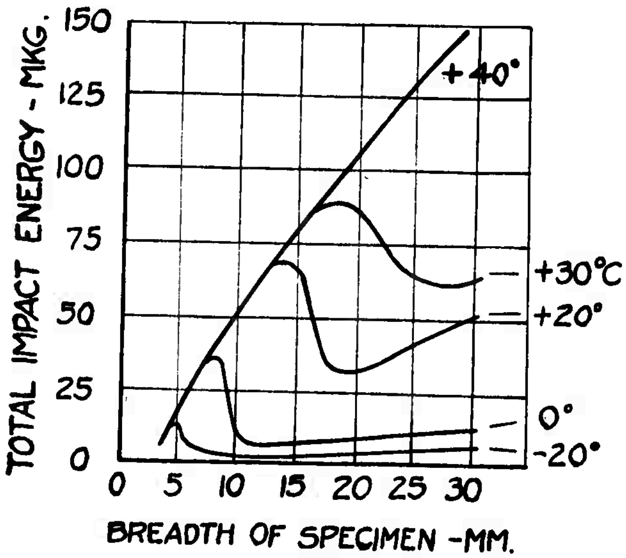


Fig. 5—Izod Test Pieces. Australian Electrode Specifications

Fig. 6—Energy of Fracture as a Function of Breadth of Specimen and Temperature of Test for Mild Steel. Length of Specimen—110 Mm. Depth Behind Notch—15 Mm. Notch—5 Mm. Deep; 45° Included Angle Velocity of Impact—5.5 M/S. (Moser 1924)



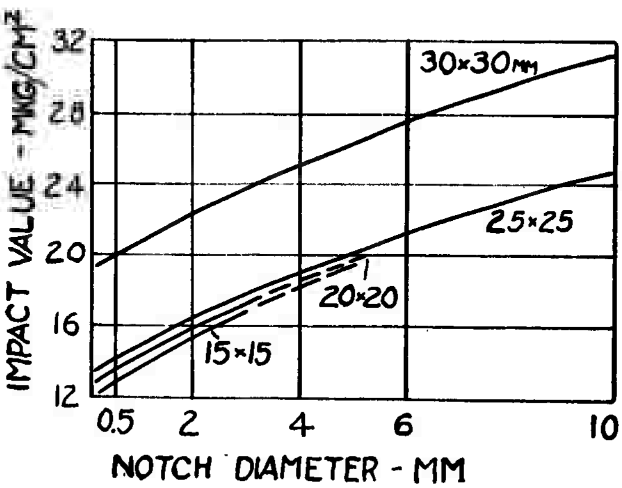


Fig. 7—Relation between Cross-Sectional Area, Diameter of Notch and Impact Value for Mild Steel at 200 °C. (Distance between Supports = 120 Mm.) (Mailander, 1926)

gave slightly higher values than the milled. As in unwelded specimens, the impact value of welded specimens of mild steel is independent of pendulum velocity between 3 and 5.2 meters per sec. A more complete series of tests on the correlation of impact values obtained on standard specimens with the results of other standard welding tests, such as tensile, bend and fatigue, would be of obvious value.

The Impact Test in General

It is not surprising that there has been no success as yet in developing rules or formulae by which to reduce the impact value of welds determined on different types of notched specimens to a value corresponding to a standard specimen. Although many reduction formulas have been suggested for unwelded materials all have failed. In spite of the fact that one of the chief recommendations of the impact test is its ability to locate the zone of transition in steel, all reduction formulas fail to account for it; nor has any proposed rule been successful in relating impact value with any of the many variables of the test.

The variation of impact value with the dimensions of specimens is much more complex than the simple beam formula would lead us to expect. Although it is well known that for a fixed form of notch and fixed total depth of specimen the impact value is roughly proportional to depth back of notch in brittle materials and to the square of the depth in tough materials, the value usually lies between these two limits, and a scatter of ±25%, according to Burns,[12] is to be anticipated. Relations between impact value and breadth of specimen have been reported and appear to be valid for some non-ferrous metals, but in view of the non-uniformity in degree of deformation across the specimen, no close relation would be implied theoretically. For mild steel the relation of breadth to impact value is by no means simple, as Fig. 6 will show.[13] The relation between impact value and cross-sectional area, as well as diameter of notch is also complex; in Figs. 7 and 8 (Honegger's Figs. 15 and 16) for mild steel at +200 and −70° C. Mailänder's[14] results show that specific impact value is independent of notch diameter only with brittle materials. He shows, too, that once a crack is formed at the base of the notch, the notch radius becomes infinitely small and the ratio of breadth to depth is increased. It is claimed that there is complete equivalence between the round and square standard British Izod specimens.

The absence of proportionality between impact value and cross-sectional area back of the notch may be due as much to design of machine as to type of specimen. With their new suspension-type of impact machine Roberts[15] and Southwell found for a number of materials that there is strict proportionality between impact resistance and cross section back of the notch. Perhaps the losses of energy in the machine foundation, in the hammer and in resonance effects, which amount to over 15% on the usual Charpy machine according to Dubois,[16] may partly account for the complex nature of impact results.

There are two variables at any rate in the impact test whose variation does not have much effect on impact value. The distance between supports may be varied without appreciable effect on impact value. If, however, the supports are brought too close together, the results are complicated by the phenomenon of shear. The effect of changing the velocity of impact within the usual limits of the machine is also negligible, except possibly in every tough material. It must be admitted that the range of velocities that has been tested is not convincingly large; whether velocities encountered in ordnance introduce other impact effects is apparently not known. Information of the sort furnished by the high-speed tensile impact tests of the Watertown Arsenal for unwelded materials would be valuable for evaluating the characteristics of welds.

Mailänder's curves, Fig. 9, showing that between four types of impact specimen there is a difference of 20° C. in the apparent position of the zone of transition forms a

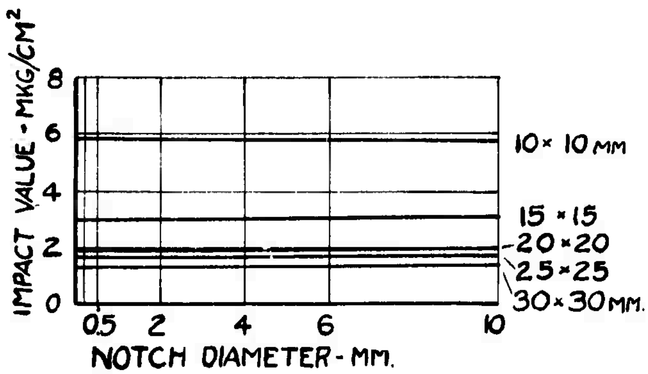


Fig. 8—Relation between Cross-Sectional Area, Diameter of Notch and Impact Value for Mild Steel at −70° C. (Distance between Supports = 120 Mm.) (Mailander, 1926)

fitting conclusion to this digression on conversion formulas. It appears that the suggestion of László[17] is still pertinent: experimentally determine curves relating all the variables in the impact test. The recent work by Burns, cited above, is a direct application of this principle. In the impact testing of all-weld-metal the principle is relatively easy to apply, but when V weld specimens are tested even this principle may be unsatisfactory. Position of notch with respect to the center line of the weld and relative percentage of overheated parent metal participating in the deformation are two knotty variables introduced by V or double V weld specimens.

Notch Location

Variations from the standard specimen have been introduced mainly to obtain a more satisfactory location of notch. Several variations of notch location are shown in Fig. 10. The notch has also been located variously with respect to center line of plate or seam; e.g., at the transition between parent metal and weld, in the overheated zone. Except that they fulfilled the immediate purpose of the particular investigator, little can be said of these variations for none has been correlated with results on standard specimens. Whether, for example, Kleiner and Bossert's modification subjects more zones of the weld to impact without introducing misleading complications, it is not yet possible to state. The standard V. G. B. specimens used different notch locations depending on plate thickness. Söhnchen and Kleinefenn[28] state that the mixed notch has about 20% higher toughness but in plate sensitive to aging this relation may be reversed. However, in double V welds, specimens with notch perpendicular to the surface of the plate have up to 20% less impact value than specimens with notch in the face of the weld. Between the three locations of notch tested by Bardtke and Matting practically no difference in Charpy value was observed. Jennings[29] also found very little difference between these three locations using the Izod notch in V welds. Hodge[30] found that the horizontal longitudinal and horizontal transverse locations of notch in weld metal gave approximately equal values but that the vertical specimen gave higher values because fracture had to extend across the original columnar crystals of the deposit. The Izod value of all-weld-metal appears to be about 50% greater when the notch is parallel to the direction of deposition than when it is perpendicular.

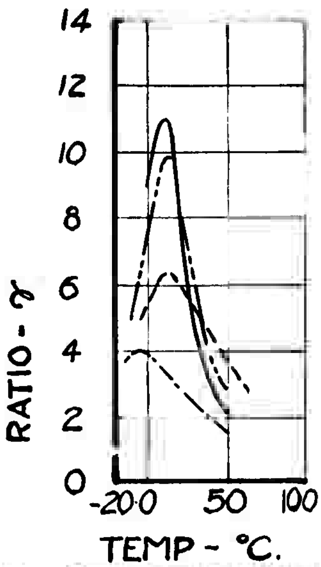


Fig. 9—Difference between Correctly Annealed and Overheated Notch-Impact Specimens of Four Different Types

$$\text{Ratio} = \frac{\text{Impact Value Correctly Annealed}}{\text{Impact Value Overheated}}$$

(Mallender, 1935)

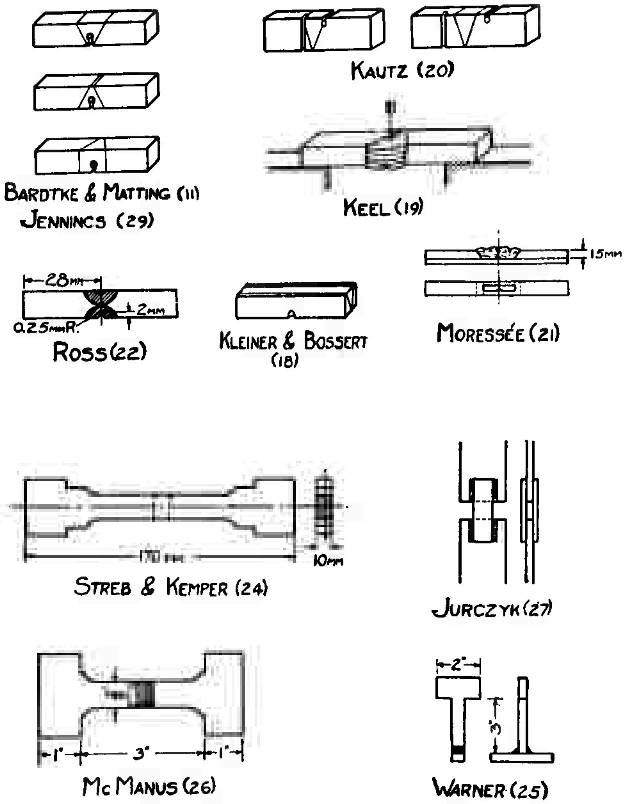


Fig. 10—Notch-Impact and Tensile-Impact Specimens Used by Various Investigators

Although a specimen such as Keel's, from which reinforcement is not removed, is advantageous in some respects, Rüter[31] and Söhnchen[28] have shown that the removal of reinforcement usually increases the impact value. It has been pointed out that from the standpoint of sensitivity to impact the most dangerous region in a welded joint is at the junction between reinforcement and parent metal. The junction acts as a notch and a photoelastic study has shown that a 70% increase in stress in the vicinity of this junction is to be expected under static load. The variation with specimen dimensions of the impact value of welds appears to follow the same rule as that which applies to unwelded material: the larger the specimen the greater the apparent toughness until, when a critical size is reached, the impact value abruptly falls with further increase in cross-sectional dimensions. On this account the Continental practice of expressing impact value as kgm./cm.^{2} of cross-sectional area is scarcely appropriate.

The single-blow impact test has often been used to test unnotched specimens of unwelded materials but the results have generally been notoriously untrustworthy. This has also been confirmed by the results of Menetrier[32] in whose tests the scatter for welds of presumably identical quality amounted in several cases to over 100% from the average. Lohmann,[33] however, found no difficulty with unnotched Charpy specimens of welds, although the unnotched gives somewhat different information from the notched specimen. The notched specimen is particularly useful for detecting the presence of embrittling metallographic constituents, such as nitrides, that are deposited during aging or in slow cooling after annealing, and for locating the temperature of the zone of transition; it does not reflect the tensile properties of weld or parent metal. The impact value of unnotched specimens, on the other hand, is increased as the strength of parent metal increases; furthermore, the zone of transition may or may not be detected, depending on chemical composition, and, in all cases, annealing a little above Ac_3 increases the impact value of unnotched specimens. Thus the unnotched specimen seems to be influenced to a greater extent by the increase in ductility (percentage elongation) than by the decrease in strength or by the precipitation of embrittling constituents consequent upon annealing. The unnotched specimen may give lower impact values than the notched if the notch extends beyond the depth of a coarsely crystallized zone, as Roš[29] has shown. Primarily, the unnotched specimen gives information about the quality of surface and junction zone, as well as about the degree of penetration.

Tensile and Repeated Impact

The desirability of testing all zones of a single welded joint in impact—with notched-bar specimens this is practically impossible—has led to the use of the tensile impact test for welds. The usual procedure for tensile impact testing is to rupture a tension specimen, usually of small cross section, so fitted in the anvil or hammer of a pendulum machine that the axis of the specimen coincides with the tangent to the path of the hammer at the instant of fracture. In this country the test has been used particularly by the Navy and Army testing laboratories, who appear to favor rather large cross sections, e.g., $^1/_2$ in. x $^5/_8$ in.; both butt and fillet welds are tested. Others who have used the test: Bock,[34] Hoffmann,[35] Fiek and Hoffmann,[36] and Streb and Kemper,[24] feel that the test would be ideal for weld testing were it not that the size of specimen is limited by the comparatively small capacity of the usual impact testing machine. The test appears to be particularly valuable as a means of determining the relative capacity of the various zones of a welded joint for deformation under impact and without the influence of a notch or, in some cases, machining. It thus indicates the extent to which the behavior of the weld resembles parent material.

The resistance of welds to repeated light impacts (impact fatigue) has also been used as a substitute for the single-blow test. The repeated impact test distinguished clearly between bare and coated electrodes in a series of tests conducted by the British E. B. & E. Insurance Co. But the Vereinigte Stahlwerke Dortmund found that the Schenck Repeated Impact machine graded electrodes according to strength, regardless of coating or nitrogen content. Joellenbeck[37] also points out that the impact fatigue value of a weld that would be classified as brittle by the single-blow test may be as high as a ductile weld. Here, too, there is lack of agreement for Rolfe's[38] tests definitely show that the results of the Stanton Repeated Impact machine on welds are similar to those of the Izod. On the other hand, there is no relation whatever between the results of the Schenck machine, using a specimen with a large-radius notch, and the values given by the single-blow Charpy impact test using notched or unnotched specimens. Thum[39] has applied the repeated-impact test to unnotched specimens of welded joints. But, strictly, this is a topic in fatigue.

A tensile-impact test of strap joints—in reality, an impact-shear test—has been used by Jurczyk,[27] and an impact shear test based on the principle of the paper cutter has been suggested by Couzin.[40] In view of the extraordinary difficulty in standardizing the well-known single-blow, notch-impact test, it is hardly to be expected that the tensile impact, impact fatigue and other proposed laboratory impact tests of whose characteristics comparatively little is known at present, will soon become prominent.

Correlations with Other Tests

In order to determine what properties the weld impact test reveals, several attempts have been made to correlate the impact value of welds or weld deposits with the results of tensile, bend, hardness, fatigue, X-ray and service tests on identical materials. As in unwelded material, there appears to be no relation between yield point, tensile strength, yield ratio, energy absorption and hardness, and the results of impact tests. Between impact value and elongation, as well as fatigue limit, there is proportionality in general, as Hoffmann[35] has shown, but the relation is by no means exact and sometimes fails to hold. The exceedingly complicated nature of the relation between impact value and reduction of area even for unwelded material is emphasized by the results of Kuntze.[42] The impact fatigue value seems to be closely related to static tensile strength, but is unrelated to the single-blow impact value.

Perhaps the most significant lack of correlation is between the impact value and the radiograph of a weld. Berthold[43] found that there is a close relation between defects revealed by radiographic examination and all mechanical properties except impact value. As Söhnchen[44] remarks, visible inclusions or blow-holes, being only one reason among many for low impact value, may greatly alter impact value depending largely, however, on their shape and distribution; the standard impact test does not, for example, detect improper fusion along the sides of the V.

The consensus of opinion in favor of the impact test for welds appears to be that the impact test measures a combination of properties embraced in no other single test and is valuable as an indication of the ability of a material to equalize stress concentrations in the vicinity of abrupt changes of section created by sudden application of heavy loads. For example, Schuster, of the British E. B. & E. Insurance Company, strongly advocates the inclusion of the test in specifications for welded boilers. The complaint expressed by some that the scatter of impact results on welds is too large may be an indication that the test distinguishes almost too sensitively between good and bad welds. For it has been clearly demonstrated that uniform impact results are obtained from uniformly good or uniformly bad welds. In the opinion of those to whom the test is superfluous, external factors, such as shape of weld, have more effect on the actual behavior of a joint than internal factors, such as blow-holes, which the test is supposed to detect. In view of the absence of correlation between impact and fatigue values, more success is obtained by eliminating notches or stress-raisers, such as surface cracks and areas of incomplete fusion or penetration, than by raising impact values.

II—Results of Impact Tests of Welds

A brief outline of the uses to which the impact testing of welds has been applied sheds additional light on the significance of the test. The test has been employed (1) to demonstrate the influence of various metallurgical factors on welded joints, (2) to pass judgment on the correct procedure to be employed in welding, and (3) to test the effect of welding on a variety of metals and alloys whether in the form of welding rod or plate to be welded.

Metallurgical Factors

1. Perhaps the greatest utility of the impact test for welds lies in its infallible detection in mild or alloy steels of constituents, such as nitrides, carbides or oxides, that have been in some way deposited in a damaging form within the metal. It was found that the impact value of

arc welds prepared with bare or ineffectively coated electrodes was invariably decreased by 10 to 50% by annealing at about 1550–1700° F., whereas gas welds were improved by such treatment. This effect was shown beyond dispute by the extensive tests of Rolfe[38] and Hopkins,[45] but Zeyen[46] was unable to detect any effect on impact by annealing. The decrease on annealing is more pronounced in low-strength than in high-strength steels. Lohmann,[33] Reeve,[47] and Söhnchen and Kleinefenn[28] have shown that, in all probability, welds containing over 0.025 to 0.05% nitrogen or oxygen, introduced by bare or improperly coated electrodes, will display this peculiar effect, which may be ascribed to precipitation of oxides or acicular nitrides during slow cooling after annealing and is not usually found after rapid cooling as in normalizing. These investigators, and Hensel and Larsen also showed that high nitrogen or oxygen content shifted the "zone of transition" to higher temperatures, and that normalizing shifted the zone to lower temperatures. Besides lowering the impact strength in the usual weld by about 25%, the V. G. B. aging test (7 to 9% stretch in tension followed by 1/2 hour at 475° F.) displaces the zone of transition from approximately −10° F. to +65° F. The danger involved in subjecting welded or other vessels to a hammer test without subsequently stress-annealing may thus be foreseen, the cold stretching of the V. G. B. test corresponding to the cold work imposed by the hammer test, and the aging treatment simulating conditions during boiler operation.

Kleinefenn[48] has extended the precipitation theory to multiple-layer welds. The normalizing effect of the upper layers on the lower layers of bare wire welds is detrimental to impact properties when the room-temperature solubility content of oxygen is exceeded. No serious loss in impact value was noted by Shepherd and Carpenter[49] in a weld containing 0.03% nitrogen that had been subjected to a variety of aging treatments. According to Wallmann and Pomp,[72] quenching followed by drawing is a more effective treatment than normalizing in raising the impact value of gas or arc welds in low-carbon steel. In gas-free welds the impact value after annealing is dependent on temperature and hence on grain size, as Schuster[8] and others have shown. Annealing temperatures above 1650° F. coarsen the grain size in plate and weld in mild steel and therefore lower the impact resistance. In gas-free, high-strength welds, such as shielded arc welds, annealing just above Ac_3 may raise the impact value at 20° C. by 30%. The relation between gas content and Charpy value has been applied by Meunier[23] to include electrolytic potential and mode of corrosion of welds. Welds with high oxygen and nitrogen contents have high electrode potentials, very low Charpy values and have a tendency to localized corrosion.

At low temperatures, e.g., −70° F., the impact value of silicon-killed mild steel plate of normal grain size is practically nil whereas the extremely fine-grained metal in the weld and adjacent heat-affected zone has a fairly high impact value 20 ft.-lb. Charpy. Hopkins[45] has found, however, that such low-temperature impact strength cannot be depended upon in service. The effect of high and low temperatures has been studied by Söhnchen and Kleinefenn,[28] Lohmann,[33] Aysslinger,[50] Blackwood[51] and Zimmermann.[52] Zimmermann's thorough investigation showed that the "zone of transition" found in mild steel, rolled or cast, is not present in gray, or malleable cast iron, and that the impact value closely followed variations in grain size and initial stresses revealed by X-ray fiber patterns. These investigations and those of Hodge[30] show that the high- and low-temperature impact characteristics of good welds are practically identical with those of parent metal. A minimum in impact value is usually found at 800 to 1000° F., for welds in mild steel; for tough welds the minimum value is usually about 50% of the impact value at 20° C.

Extensive series of tests by Hodge, Rolfe and the British E. B. & E. Insurance Company have shown that the so-called dangerous, coarse-grained junction zone between weld and parent metal has as good impact resistance as the weld or the original plate. Hopkins' micrographs suggest that the junction zone can be made fine-grained throughout with the proper welding technique. However, if the zone is partly or wholly coarse-grained, its sorbitic structure will probably offset to some extent the sensitivity to impact. Besides, in non-aging steels, grain growth is not accompanied by loss of impact resistance. Fry[53] and Beckmann[54] have demonstrated that the martensitic junction zone in austenitic welds in Izett plate has excellent impact properties equivalent to those of tough mild steel. Although in hand and machine flame cutting it might be presumed that the metal adjacent to the cut surface is more rapidly cooled and hence more brittle than the junction zone in welds, Zimmermann[55] as well as Wiss (1909, 1929) and Rambuschek (1925), found, on the contrary, that the machine-cut surface layer has the same impact value as the original structural steel. Hand torch cutting definitely improves the impact value of the surface.

The remarkable improvement in the impact resistance of welded structures, such as pressure vessels, by a stress anneal at about 1200° F. is not reflected to the same extent in Charpy or Izod value. The act of cutting a small specimen from a seam automatically relieves shrinkage and other internal stresses. On this account the high impact value of welds in rigidly clamped or highly stressed plates, found by Daeves, Buchholz and Hochheim, must be interpreted with caution. Prox,[56] Zimmermann[52] and Stiller[57] have found a little improvement in notch impact value by stress annealing. Experience (private communication, H. L. Whitney) in this country has shown that the usual 25 ft.-lb. Charpy obtained in welds in silicon-killed plate is increased to about 29 ft.-lb. or higher after stress annealing at 1200° F.

The fracture of the impact specimen, distributed as it is between cleavage and shear to different extents in different specimens depending upon heat treatment and gas content, is of limited value in detecting improper welding procedure, according to Lefring.[58] For this purpose, however, the nick-break test specified by the American Welding Society is probably more suitable.

Factors Related to Process

2. The impact test has probably been of most service to the welding industry in demonstrating the benefits to be derived from effectively coated welding rods. Tests by a large number of investigators conclusively demonstrate the superior impact resistance of heavily-coated electrodes, particularly of the shielded-arc type. The advance in Izod value from 5 ft.-lb. with bare wire in 1920 to 40 ft.-lb. easily obtained at present with any good quality electrode has been rapid and continuous. Rods for gas welding have not received quite so much attention. Unannealed gas welds generally have not more than 80% of the impact value of the parent metal, carbon arc welds (unprotected) approximately 20 to 40%. But values as high as 100% have been reported[72] in heat-treated, automatic carbon-arc welds made in hydrogen. The low values for gas welds are due to coarse grain, which is sometimes even coarsened by annealing. Water-gas welds, according to Sirovich,[59] may exceed the

parent metal in impact value, and butt resistance welds, as Wuppermann[60] has shown, also have dependable impact properties. The ends of the lap in water-gas welds often show lower values than the middle of the lap or the parent metal.

The impact test has also been used to show the improvements to be derived from multiple-layer welding, reverse runs (tests of arc welds by Swiss Boiler Owners Association, 1921) light top runs and torch annealing. The case for multiple-layer welding is perhaps most clearly stated by Guerrera,[61] who showed that a 2-run arc weld had three times the impact value of a single-run joint, both welds being made with heavily coated electrodes. The larger amount of coarse cast structure in the single-run joint accounted for this difference. Guerrera demonstrated that the continuous band of coarse Widmannstätten structure in the heat-affected zone of the single-run weld was more susceptible to impact fracture than the patches of this undesirable structure that are found in multiple-layer welds. Multiple-layer welding generally gives a further increase of up to 100% in impact value over the two-run weld. But multiple-layer welding does not counteract the brittleness of bare-wire welds. Helin and Svantesson[62] found that multiple-layer welds in which each layer was allowed to cool before the next layer was deposited had about 25% higher impact values than welds in which no time for cooling was allowed. In gas welding the well-known beneficial effect of a reverse run (C. F. Keel), or a light top run on impact value was probably first announced by Buchholz[63]; a reverse run is usually as effective as annealing in increasing the impact value of gas welds by 50 to 100%.

Since impact value responds far more to a change in gas content or grain size than to a change in internal stress, Hoffmann[41] maintains that the high impact value obtained with covered electrodes or certain types of torch annealing is counterbalanced to some extent by the high shrinkage stresses. Peening and also forging of a finished weld, is beneficial to impact value; increases of 10 to 100% have been reported. As plate thickness is increased from $^3/_8$ to $^3/_4$ inch the impact value of all types of welds tends to decrease in comparison with parent metal; the increase in impact value produced by hot forging after welding is greater in the thinner plate. The effect of current strength on impact value, studied among others by Roux,[64] is relatively small although unusually high or low current lowers the impact value. Success with high-current welding was obtained by Ross[22] only with specially fluxed electrodes. The effect on impact resistance of A.C. as compared to D.C., of polarity and of arc length have also received attention (Moon[65]), but no effect of any magnitude was discovered. Within wide limits the quality of a flame cut bevel is without effect on the impact value of the joint. Back-hand welding, because it gives rise to less severe overheating, is preferable to fore-hand from the standpoint of impact resistance of welds in steel, according to Hermann[66] and Buchholz,[63] but Hunsicker[67] finds that the reverse appears to be true for welds in copper.

Chemical Composition and Alloying

3. There is little published information dealing with the effect of alloying on impact value of welds in steel. Gas and arc welding rods give somewhat better impact value if the carbon and manganese are on the high side (0.2% C, 1.0% Mn) than if they are on the low side (0.1% C, 0.5% Mn), according to Streb and Kemper.[24] The low impact value of welds made with bare electrodes, usually about 5 ft.-lb., may be increased by 5 to 10 ft.-lb. by addition of 2% Mn or 0.3 Cr, 0.8 Cu, to the electrode. Otherwise, electrode analysis, considering the usual elements, C, Si, Mn, plays a minor rôle in comparison with the composition of the covering. Although plate composition has considerable influence on the impact value of welds below −10° F., Lohmann[33] has shown that it has no influence at +65° F. if covered electrodes are used. Hence, the effect of diffusion of elements from plate to deposit is probably completely masked by other factors. Shielded-arc welds in high-pressure steam piping (0.33% C, 0.75% Mn) and also in castings (0.24% C, 0.6% Mn, 0.8% Mn, 1.2% Ni, 0.4% Mo) develop good impact values at room temperature (30 to 40 ft.-lb. Charpy) and fair values even at 850° F. (16 to 20 ft.-lb. Charpy). Zeyen[46] showed that the impact value of welds rapidly decreased as the carbon content increased up to 0.3% but decreased much less rapidly thereafter up to 0.7% C. Similar observations have been made by the British E. B. & E. Insurance Co., who report a 50% decrease in Izod value as carbon is increased from 0.1 to 0.3%, and who find that in mild steel, sulphur up to 0.12% has no effect on impact properties but that an equal amount of phosphorus has an adverse effect. The small cracks of microscopic dimensions and undesirable microstructure almost always found in the junction zone of welds in steels containing more than 0.3% C probably account for their comparatively low impact resistance.

Söhnchen and Kleinefenn[28] give perhaps the best recent treatment of the subject of alloying although their chief interest is in nitrogen and oxygen content. Nevertheless they state that nickel provides positive protection against mechanical aging. Except in A.C. arc welds, nickel, chromium, vanadium or molybdenum had no effect on the location of the "zone of transition" and had little effect on impact value in general. This experience was reported also by Roš[68] and Sommer.[69] Streb and Kemper, however, obtained excellent impact values for welds in high-strength structural steels using rods containing $3^1/_2$% Ni, 0.15% C or 1% Cr, 0.3% C. In their paper at the I. & S. I. Symposium, 1935, they report high impact values in mild steel and high strength copper steel using rods containing 2 to $3^1/_2$% Ni. Rods containing 0.6% Si gave high tensile impact values (250 ft.-lb.) as welded but were only slightly improved by annealing. (30% increase as compared with over 200% for Mn and Cr-Ni rods.) Hopkins and McAllister[70] also find good impact values for nickel steels (15 ft.-lb. Charpy at −70° F.). Hatfield[71] states that the best impact resistance of the 3% Ni welds is developed only after full annealing or stress annealing. The tensile impact value of high-grade covered electrodes is increased from 500 without nickel to 1400 ft.-lb. with $3^1/_2$% Ni or 0.25% Mo. Hopkins, however, found somewhat better impact properties for the $2^1/_4$% Ni steel (35 ft.-lb. Charpy at 70° F.) than for the $3^1/_2$% Ni (25 ft.-lb. stress-annealed) but both were superior to low-manganese steels (0.25% C, up to 2% Mn (20 ft.-lb. stress-annealed)). The impact value of the nickel steel weld at −75° F. is reduced to about 4 ft.-lb. Charpy by overheating at 1900° F., but the as-welded value of 25 ft.-lb. is restored by heating to 1525° F. for 1 hour. Stress-annealed welds in cast carbon-molybdenum steel (0.3% C, 0.4–0.6% Mo, Crane Valve Steel) give 29.5 ft.-lb. Charpy. Promper and Pohl also report good impact values for welds in rolled molybdenum steel (0.15% C, 0.34% Mo) both at 20 and 500° C. Despite their poor weldability, high-silicon steels (0.15% C, 1.1% Si, 0.9% Mn), according to Grahl,[73] possess good impact properties (30 ft.-lb. Charpy) above 120° F. when flash welded; below 120° F. the zone of transition is encountered and the Charpy value drops below 5 ft.-lb.

Hessler and Kautz[74] and others state that the impact value of welds made in Izett IV steel using the Krupp austenitic electrode (20% Ni, 25% Cr, 0.1% C, 1.5% Mn, 0.75% Si) are remarkably good (60 ft.-lb. DVMR) in all parts of the welds and its vicinity. Although the impact value of welds in 18% Cr iron is low,[41] about 4 ft.-lb. Charpy, an anneal at 1500° F. raises the toughness to 20 ft.-lb. In 18–8 the addition of 1.3% Ta or 0.5% Ti eliminated notch sensitivity in the weld, thus eliminating heat treatment. Arc welds in 18–8, as described by Hessler and Kautz,[97] have excellent impact properties (330 ft.-lb. V. G. B.) though not so high as the unwelded material (525 ft.-lb. V. G. B. unbroken); unless a precipitation inhibitor is added to plate and weld the joint should be water quenched from about 2000° F.

The impact value of non-ferrous welds is a neglected subject. Beyond notes by Brillié[75] on brazing solder, by Hunsicker[67] on copper, and by Bartels[76] and Zimmermann[52] on aluminum and silumin, there has been little published recently on the impact resistance of non-ferrous welds. In his excellent treatise on the temperature variation of impact resistance, Zimmermann showed that acetylene-welded aluminum was more brittle than unwelded aluminum, which could not be ruptured in the impact machine, but that the welds were nearly as resistant to impact at 200° C. as at −200° C. Silumin was much more brittle. Bartels studied the impact fatigue of aluminum, silumin and copper, as well as cast iron and steel. Cast iron, as welded, has about the same impact fatigue resistance (600–1000 blows of the 3 kg. load in the Krupp Repeated Impact Machine) as welds in mild steel; the results on the non-ferrous metals show that the resistance to repeated impact of welds in aluminum and copper is much lower than that of unwelded metal. Hunsicker found that hammering at red heat or annealing at any temperature up to 1000° C. had no effect on the notch-impact value of V and double V welds in copper. Brazing solder, according to Brillié, loses most of its impact resistance after deposition in the joint.

III—Service Tests and Service Results

Service Tests

Impact tests are often performed on Charpy or Izod specimens cut from the welded joints of a completed structure, as described by Czternasty[77] for pressure vessels and by Nápravník and Popov[78] for resistance welded chain. Unfortunately, such specimens, in many cases, do not reproduce the stress conditions existing in the actual joint although service tests have shown that joints of low impact value fail suddenly whereas joints of high impact value fail slowly, cracks propagating only in the highly-stressed area. Unrelieved shrinkage stresses in a welded seam undoubtedly lower its impact resistance although there is no quantitative information on the subject. Interesting applications of an impact testing machine to the testing of full-sized structural elements have been made by Longoni[79] and Roark.[80] Longoni uses the two approximate relations within the elastic limit: (1) that impact stresses in rods of the same length under tension impact are inversely proportional to the square root of the (uniform) cross section, and (2) that the impact stresses in centrally loaded simple beams of the same length are directly proportional to the section modulus. He gives the results of impact tests of welded C-bars of different designs (Fig. 11), which substantiate his conclusions that geometrical shape is the dominant factor in comparing impact resistance of structural elements and that a weld on account of its comparatively small volume, absorbs only a small fraction of the total elastic deformation of a member under impact. Although similarity exists in the elastic region, there is probably no similarity rule for the plastic region. Hence the behavior of large structures under impact cannot accurately be deduced from tests of small models in the ordinary impact machine.

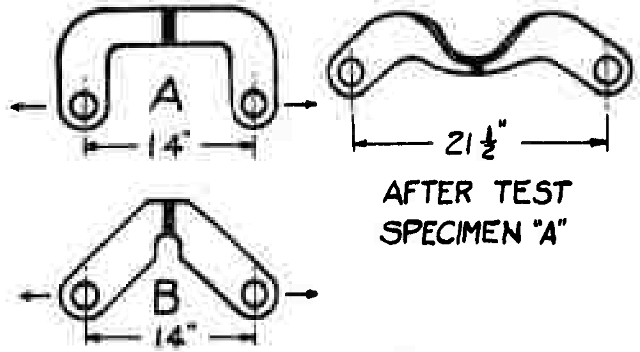


Fig. 11—Butt-Welded C-Bars

Cross Section at Weld	Comparative Strength Static	Comparative Strength Impact
Specimen B = 3 In. × 5/8 In.	100%	100% (15 In.-Tons)
" A = 3 In. × 5/8 In.	100%	Over 200% (30 In.-Tons, Unbroken)
" B = 3 In. × 1 In.	266%	About 200 %

(Longoni, 1934)

The hammer test, often specified, and fully formulated in the Boiler Code of the Standards Association of Australia, is a variety of service impact test on highly stressed pressure vessels. A typical instance in which the hammer test was successfully applied is described by van Norman[81]; the combined pressure and hammer test revealed only two leaks in the Bouquet Canyon pipe line. If the hammer test is made too severe it may cause permanent, though undetected, damage. According to Shepherd and Carpenter,[49] the hammer or pressure impulse test is used only on relatively unimportant pressure vessels where the cost of an X-ray examination would not be justified.

A sub-zero hammer test for pressure vessels is described by Hopkins.[82] In this test the welded vessel was held for 12 hours at −50° F. under 250 psi pressure. The nickel steel vessel was then removed from the cooling bath for tests; the welded seam withstood hammering along its center as well as on both sides. A test set-up for subjecting welded acetylene generator receivers to explosions is described by Rimarski[83]; the welded receivers were not ruptured even by oxyacetylene explosions that exerted 300 atmospheres pressure. Burkhardt[84] has shown that a welded construction remained unaffected by an under-water explosion that started the seams of a similar riveted construction.

Another service impact test that is often used is the drop-hammer or tup test for welded rail joints. The procedure and results as described by Csilléry,[85] Rietsch and Croskell,[86] the Committee on Welded Rail Joints and Keel[87] show that the number of drops of a heavy ram from a fixed or increasing height which a joint will withstand when supported as a simple beam, is a satisfactory measure of the quality of joint. This test is sometimes used for structural welds, such as bearing joints in bridges and was used by Couzin[40] to show the quality of a welded staircase. Paton[88] and his co-workers have shown that, under repeated heavy impact, welded beams are superior to riveted beams of equivalent static strength. In drop-testing welded demolition bombs the bombs themselves act as the ram. The maximum diameter of the projectile must penetrate at least one foot below the surface of the concrete. Bombs welded according to the A. S. M. E. Code for Class I pressure vessels successfully pass this test. A particularly severe test of welds made according to the Class I Code was made by the A. O. Smith Corporation who dropped a 1700-lb. skull cracker from a height of about 30 feet on the shielded-arc welded seams of 30-inch pressure pipe under 1000 psi internal pressure and also on a large helium container 7 feet in diameter and under 2000 psi pressure. Tests of welded nickel-chrome armor plate with armor-piercing bullets by the Watertown Arsenal revealed no brittleness even at unusually high impact velocities. That there is nothing inherent in welds to make them sensitive and weak under impact loads is shown by the successful behavior of welds made with bare electrodes as long ago as 1924.[89]

Rail welding rods are evaluated by Keogh[90] by machining Izod specimens from a thick pad deposited on top of the rail. Specimens with notches at critical locations in deposit and junction zone are then tested. Similar tests are described by Bruneteau[91] for welded-on rail overlays. A significant example of the high service impact resistance of welded railway wagons is given by the tests of Ashworth and May[92] for the Victorian Railways, Australia. Racking and buffing tests of unusual severity had no effect on welded wagons but were too much for riveted wagons. Similar results were obtained in tup tests of welded underframes by Metropolitan Cammell's works.

Service Results

Satisfactory results from welded joints have not been confined to the railroads. In the following concluding paragraphs a few especially striking instances are referred to that show the general reliability of welds under impact.

Experience in the last earthquake in the Los Angeles area showed that the most reliable joint for buildings and piping in the earthquake district is the welded joint. According to eye-witnesses at the last 'quake there were no failures of welded pipe joints even in the complicated systems of the oil refineries except under extremely unfavorable circumstances. School buildings in the earthquake areas are now being erected almost exclusively with the aid of welding.

In marine construction welding is now perhaps the chief method of fabrication. On a number of occasions welded ships have been returned to service after severe collisions by merely hammering out dents, as in the case of the Fullagar. Similar experiences have been recorded with a large number of tugs, barges and similar roughly handled craft.[93] A good example of the additional safety involved in the use of welded ships' ventilator fans is shown by Zeriali.[94] No weld failed when a foreign body accidentally passed through the high-speed fan.

Although many all-welded bridges and cranes have been built both in this country and abroad no failure has been recorded. The customary practice in bridge design is to add 30 to 60% to the maximum computed live load stress to take care of the dynamic increment in floor beams, hangers and stringers. There are indications that a fatigue factor will displace this "impact allowance." The capacity for distortion without rupture of a bare-wire fillet-welded mobile crane is shown by Griffin.[95] This heavy-duty crane was severely crumpled in a collision with an overhead bridge; since none of the welds failed the crane was straightened and performed satisfactorily thereafter. Another example of the resistance to impact of welded joints was afforded during the demolition of the Sky-Ride Towers at the Chicago World's Fair.[96] Examination of the distorted structures of aircraft after crashes almost invariably reveals that the welds have not failed.

Welded piping and casing for foundations and pipe lines have withstood a number of severe impact tests. The welded pipe used as piling by the Western Foundation Company of Chicago in the foundations of the Cincinnati Times-Star building received 40 blows of a 5000-lb. hammer followed by aligning without fracture. An unexpected impact test of gas-welded piping occurred when 40 lengths of 16-in. pipe line slid 60 feet down a steep hill when the emergency anchor slipped. Despite buckling and severe distortion in the pipe, there was not a single failure in the welds.

The toughness of welds in 18-8 is shown in some tests by Hessler and Kautz[97] on a 2300-gallon, arc-welded beer tank in V2A (18-8). The tank filled with water, was pushed off a low platform onto an uneven floor; the welds were dented but the tank remained leaktight. After the dents were hammered out the tank was placed in service and performed satisfactorily. They also describe the effects of an accidental explosion in a welded V2A tank; the vessel was severely crumpled but again the welds remained tight.

The Welded Rail Joint Committee[98] of the American Bureau of Welding made a large number of impact and repeated impact tests on various types of street railway joints (about 0.75 carbon) and in all of these investigations the superiority of thermit and resistance welded joints was noticeable as compared with the arc-welded joints using fish plates. A great deal of this superiority was undoubtedly due to the form of the joint, but the results indicated the excellence of the physical properties of welds made by the thermit and resistance butt processes. Many tests of spot welds made by one of the authors in which an attempt was made to break the "spot" with a sledge-hammer, invariably resulted in pulling out a piece of the parent metal.

IV—References and Selected Bibliography*

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1 D. I. N. Vornorm 1913 March 1934. Specifications for Welding Wire for Gas and Arc Welding; also D. I. N. Vornorm Entwurf DVM-A115.

2 Önorm B2332, 1934. Austrian Standards Institution. Directions for the Design and Erection of Welded Steel Structures.

3 Specification of the Joint Commission of Société des Ingénieurs Soudeurs and Institut de Soudure Autogène, 1935. *Rev. Soud. Autog.*, **27**, (257), 2–10, July 1935; also *Le Soudeur-Coupeur*, **10**, 1–8, April 1935.

4 Rules for Construction and Classification of Steel Ships; also Specifications for Stationary Structures. Le Bureau Veritas, Paris, 1934.

5 Instructions for the Erection of Arc-Welded Structures and Bridges. Ministry of Public Works, France. *Ann. des. Ponts et Chaussées*, **105**, 303–322, 824–828 (1935).

6 British Standard Specification No. 538–1934, for Metal Arc Welding as Applied to Steel Structures, March 1934; also No. 639–1935 Covered Electrodes and No. 640–1935 Bare Rod or Wire Electrodes for Metal Arc Welding Wrought Iron and Mild Steel, Dec. 1935.

7 Standards Association of Australia, Code for Metallic Arc Welding in Steel Buildings. June 1933. No. CA 8–1933.

8 Schuster, L. W., *Proc. Instn. Mech. Eng.*, **124**, 569–599 (1933).

9 British E. B. & E. Ins. Co., 1928.

10 Dustin, H., and Rosenthal, D., Int'l. Assoc. for Testing Materials, Zurich, 1932. I. 409–411.

11 Bardtke, P., and Matting, A., *Autog. Metallb.*, **26**, 290–293 (1933).

12 Burns, G., *Metallurgist*, Dec. 1935, 86–88.

13 Honegger, E., *Schweiz. Verb. Materialprüfung der Technik. Ber.* No. 5, 3–16 (1927).

14 Mailänder, R., *Stahl u. Eisen*, **55**, 749–754 and 779–786 (1935).

15 Roberts, A., *Engineering*, **137**, 112–116 (1934).

16 Dubois, F., *Machines*, July to October 1935.

17 László, F., *Stahl. u. Eisen* **34**, 1413–1422 and 1521–1525 (1925).

18 Kleiner, H., and Bossert, K., *Autog. Metallb.*, **27**, 131–139 (1934).

19 Keel, C. F., *J'l. de la Soudure*, **22**, 12–13, Jan. 1933.

20 Kautz, K., *Techn. Mitt. Krupp.*, **3**, 143–173 (1935).

21 Moressée, G., *Rev. Univ. des Mines*, **78**, 345–361 (1935).

22 Ross, R., *Modern Engr*, **8**, 141–148 and 169–176 (1934).

23 Meunier, F., *Compt. Rend.*, **196**, 271–273 (1933).

24 Streb, E., and Kemper, H., *Autog. Metallb.*, **26**, 2–8 (1933); also I. & S. I. Symposium, 1935, II, 573–591.

25 Warner, W. L., Am. Welding Soc. Jour., **13**, 15–23, June 1934.

26 McManus, T. K., Am. Welding Soc. Jour., **10**, 16–19, Jan. 1931.

27 Jurczyk, K., *Elektroschw.*, **5**, 26–33 (1934).

28 Söhnchen, E., and Kleinefenn, W., *Elektroschw.*, **6**, 181–185 (1935).

29 Jennings, C. H., Am. Welding Soc. Jour., **9**, 90–104, Sept. 1930. Also Roš, M., and Eichinger, A., *Eidgen Mat. Prüf. Anst. E. T. H. Zurich Ber.*, **86**, March 1935.

30 Hodge, J. C., Am. Welding Soc. Jour., **13**, 12–17, Jan. 1934.

31 Rüter, E., *Z. VDI.*, **77**, 917–920 (1933).

32 Menetrier, A., Am. Welding Soc. Jour., **3**, 13–17, Jan. 1924.

33 Lohmann, F. W., *Mitt. Forsch.-Inst. Vereinigte Stahlwerke, Dortmund*, **3**, 267–294 (1932–1933).

34 Bock, E., *Maschinenbau*, **4**, 979–984 (1925). Also *Arcos*, **9**, 697–706 (1932).

[35] Hoffmann, W., *Stahlbau*, **7**, 85–87 (1934).
[36] Fiek, G., *Elektroschw.*, **5**, 67–71 (1934). Also Hoffmann, W., *Elektroschw.*, **5**, 138 (1934).
[37] Joellenbeck, E., and Massmann, C., *Elektroschw.*, **2**, 165–169 (1931).
[38] Rolfe, R. T., I. & S. I. Symposium, 1935, II, 539–552.
[39] Thum, A., and Lipp, T., *Giesserei*, **21**, 41–49, 64–71, 89–95, 131–141 (1934).
[40] Couzin, S., *Jl. S. Afr. Instn. Engrs.*, **30**, 231–249, 320–324 (1932).
[41] Hodge, J. C., *Metal Prog.*, **27**, 33–38, April 1935.
[42] Kuntze, W., *Arch. Eisenhüttenwes.*, **2**, 583–593 (1928–1929).
[43] Berthold, E., *Z. VDI*. **79**, 960 (1935).
[44] Söhnchen, E., *Elektroschw.*, **6**, 155–157 (1935).
[45] Hopkins, R. K., Am. Welding Soc. Jour., **13**, 16–28, Oct. 1934, and **14**, 4–7, March 1935.
[46] Zeyen, K. L., I. & S. I. Symposium, 1935, II, 617–633.
[47] Reeve, L., I. & S. I. Symposium, 1935, II, 517–529.
[48] Kleinefenn, W., *Carnegie Schol. Mem.*, **22**, 97–133 (1933).
[49] Shepherd, T. C. R., and Carpenter, S. W., I. & S. I. Symposium, 1935, II, 161–179.
[50] Aysslinger, H., *Mitt. Forsch. Anst. GHH. Konzerns.*, **2**, 135–140 (1932–1934).
[51] Blackwood, R. R., *Jl. Instn. Engrs. Australia*, **6**, 421–443 (1934).
[52] Zimmermann, F., *Ber. Inst. Mech. Tech. u. Materialkunde, Techn. Hochsch.*, Berlin, 4 (1934).
[53] Fry, A., *Elektroschw.*, **4**, 201–208 (1933).
[54] Beckmann, E., *Techn. Mitt. Krupp*, **3**, 137–142 (1935).
[55] Zimmermann, J. H., *Proc. Intl. Acet. Assn.*, **1934**, 88–99; also Hovey, O. E., Am. Welding Soc. Jour., **10**, 24–25, June 1931.
[56] Prox, W., *Z. VDI.*, **76**, 497–504 (1932).
[57] Stiller, E., *Elektroschw.*, **5**, 230–232 (1934).
[58] Lefring, N., *Forshungsarbeiten VDI*. No. **332** (1930).
[59] Sirovich, G., *Met. Ital.*, **25**, 502–524, 569–598, 653–672, 725–740, 799–824 (1933).
[60] Wuppermann, T., *Z. VDI.*, **73**, 1758–1763 (1929).
[61] Guerrera, U., I. & S. I. Symposium, 1935, II, 277–279.
[62] Helin, E., and Svantesson, S., I. & S. I. Symposium, 1935, II, 373–390.
[63] Buchholz, R., *Autog. Metallb.*, **24**, 288 (1931).
[64] Roux, A., *Technique Moderne*, **19**, 105–110 (1927).
[65] Moon, A. R., *Jl. Instn. Engrs. Australia*, **2**, 258 (1930).
[66] Hermann, F., *Autog. Metallb.*, **26**, 145–150 (1933).
[67] Hunsicker, L., *Autog. Metallb.*, **28**, 275–282, 289–297 (1935).
[68] Roš, M., *Schweiz. Verb. Materialprüfung der Technik. Ber.* No. **5**, 17–59 (1927).
[69] Sommer, F., *Autog. Metallb.*, **26**, 22–27 (1933).
[70] McAllister, L. P., *Welding Engr.*, **20**, 30–32, May 1935.
[71] Hatfield, W. H., I. & S. I. Symposium, 1935, II, 363–371.
[72] Wallmann, K., and Pomp, A., *Mitt. KWI. Eisenforsch.*, **14**, 271–294 (1932).
[73] Grahl, H., *Arch. Eisenhüttenwes.*, **4**, 593–600 (1931).
[74] Hessler, R., and Kautz, K., *Wärme*, **58**, 511–519 (1935).
[75] Brillié, J., *Le Soudeur-Coupeur*, **14**, 1–4, Nov. 1935.
[76] Bartels, B., *Ber. Inst. Mech. Tech. u. Materialkunde, Techn. Hochsch.*, Berlin, 3 (1930).
[77] Czternasty, G., *Z. VDI.*, **76**, 679–682 (1932).
[78] Nápravník, V., and Popov, S., I. & S. I. Symposium, 1935, I, 513–526.
[79] Longoni, A. J., *Modern Engr.*, **8**, 188–193, 212–215, 231 (1934).
[80] Roark, R. J., Am. Welding Soc. Jour., **7**, 57–64, Feb. 1928.
[81] van Norman, H. A., *Civil Engg.*, **4**, 306–310 (1934)
[82] Hopkins, R. K., *Metals Technology*, **2**, Aug. 1935.
[83] Rimarski, W., and Friedrich,—., *Autog. Metallb.*, **26**, 49–54 (1933).
[84] Burkhardt, —., *Elektroschw.*, **3**, 189 (1932).
[85] Csilléry, D., *Elektroschw.*, **6**, 25–33 (1935).
[86] Rietsch, E., and Croskell, A. C., I. & S. I. Symposium, 1935, I, 339–347.
[87] Keel, C. F., *Jl. de la Soudure*, **22**, 88–98, April 1932. Also Reiter, M., *Org. Fortschr. Eisenbahnwes.*, **85**, 1930, 419–432.
[88] Paton, E. O., and Diatlov, A. V., Am. Welding Soc. Jour., **10**, 39–43, June 1931.
[89] Goldmark, H., Spraragen, W., and Warner, W. L., Am. Welding Soc. Jour., **3**, 27–69, Oct. 1924.
[90] Keogh, C. P., *Modern Engr.*, **8**, 220–225, 242–247 (1934).
[91] Bruneteau, M., *Rev. Soud. Autog.*, **26**, 8–12, Sept. 1934.
[92] Ashworth, J. M., and May, H. N., I. & S. I. Symposium, 1935, I, 299–306.
[93] *Trans. Soc. Naval Arch. & Marine Engrs.*, **42**, 232 (1934).
[94] Zeriali, G., I. & S. I. Symposium, 1935, I, 609–618.
[95] Griffin, R. G., I. & S. I. Symposium, 1935, I, 565–571.
[96] Wilson, A. L., *Welding Engr.*, **20**, 24–27, July 1935.
[97] Hessler, R., and Kautz, K., *Elektroschw.*, **5**, 81–88 (1934).
[98] Committee on Welded Rail Joints Final Report, New York, Sept. 1932.